

BABYSCAN – a whole body counter for small children in Fukushima

Ryugo S. Hayano*

*Department of Physics, The University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*

Shunji Yamanaka

*Department of Mechanical and Biofunctional Systems,
Institute of Industrial Science, The University of Tokyo,
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan*

Frazier L. Bronson and Babatunde Oginni

Canberra Industries, Inc., 800 Research Parkway, Meriden, CT 06450, U.S.A.

Isamu Muramatsu

Canberra Japan KK, 4-19-8 Asakusabashi, Taito-ku, Tokyo 111-0053, Japan

BABYSCAN, a whole body counter for small children with a detection limit for ^{137}Cs of better than 50 Bq/body, was developed, and the first unit has been installed at a hospital in Fukushima, to help families with small children who are very much concerned about internal exposures. The design principles, implementation details and the initial operating experience are described.

Keywords: Fukushima Dai-ichi accident, radioactive cesium, whole-body counting, radiological protection

I. INTRODUCTION

The Fukushima Dai-ichi NPP accident [1] contaminated the soil of densely-populated regions of Fukushima Prefecture with radioactive cesium, which poses risks of internal (and external) exposures to the residents. If we apply the knowledge of post-Chernobyl accident studies [2], internal exposures in excess of several mSv y^{-1} would be expected to be frequent in Fukushima.

Extensive whole-body-counter surveys of 21,785 residents in highly-affected Fukushima municipalities, however, showed that their actual internal exposure levels are much lower than estimated [3]; in 2012–2013, the ^{137}Cs detection percentages (the detection limit being ~ 300 Bq/body)

*Correspondence should be addressed: R. Hayano, (hayano@phys.s.u-tokyo.ac.jp).

are about 1% for adults, and practically 0% for children (age 6–15). These results are consistent with those of many other measurements and studies conducted so far in Fukushima, e.g., rice inspection, foodstuff screening and duplicate-portion studies.

Nevertheless, there continue to be many residents, families with small children in particular, who are very much concerned about internal exposures. This is in part due to the fact the WBCs currently being used in Fukushima, such as the FASTSCAN [4], are designed for radiation workers, who are adults. Children have been successfully measured previously at Chernobyl, and in Fukushima Prefecture, by having them stand on a small stool to get their bodies into the detection zone. While this is suitable to measure larger uptakes in larger children, it is not optimum for measuring small children ($\lesssim 4$ y), and is not suitable for infants or children who cannot stand.

Scientifically, it is sufficient to measure parents, but worried parents strongly request to have their babies measured. We therefore launched a project in the spring of 2013 [5] to develop a whole body counter for small children called a “BABYSCAN”, and have installed the first unit at the Hirata Central Hospital in Fukushima Prefecture in December 2013. The design principles, implementation and the initial operating experience are reported.

II. BABYSCAN REQUIREMENTS

About 80% of some 60 WBCs currently installed in Fukushima Prefecture are Canberra’s FASTSCAN. A subject stands for two minutes in a shielding box made of iron, which houses two $7.6 \times 12.7 \times 40.6$ cm sodium iodide (NaI) gamma-ray detectors. The detection limit for radioactive cesium is about 250-300 Bq/body (both for ^{134}Cs and ^{137}Cs), which is nearly independent of height and/or weight of the adult subject (flat within $\sim \pm 15\%$).

This detection limit is however too high for reliably measuring small children, since the biological half-life of radioactive cesium in children (~ 13 days for 1-year old, ~ 30 days for 5-year old) is much shorter than that in adults (~ 110 days). As a result, children’s internal contamination is harder to detect.

For example, if an adult ingested 3 Bq of ^{137}Cs every day, the body burden would reach an equilibrium plateau of ~ 400 Bq/body [6]. This can be detected by the FASTSCAN. If on the other hand a 1-year-old child ingested the same amount, the resultant body burden would be $\sim 60\text{Bq/body}$. Therefore, the WBC for babies must have a much lower detection limit.

Our goal was to achieve a detection limit of < 50 Bq/body for $^{134,137}\text{Cs}$. In order to realize this high sensitivity, the BABYSCAN must be ergonomically designed so that a small child can stay

still for several minutes, without feeling afraid of confinement.

From the beginning, it was recognized that the BABYSCAN's design must be reassuring to parents, and that in addition to being a measurement device, it would be expected to play an important role as a communication tool to facilitate interactions between medical staff and residents.

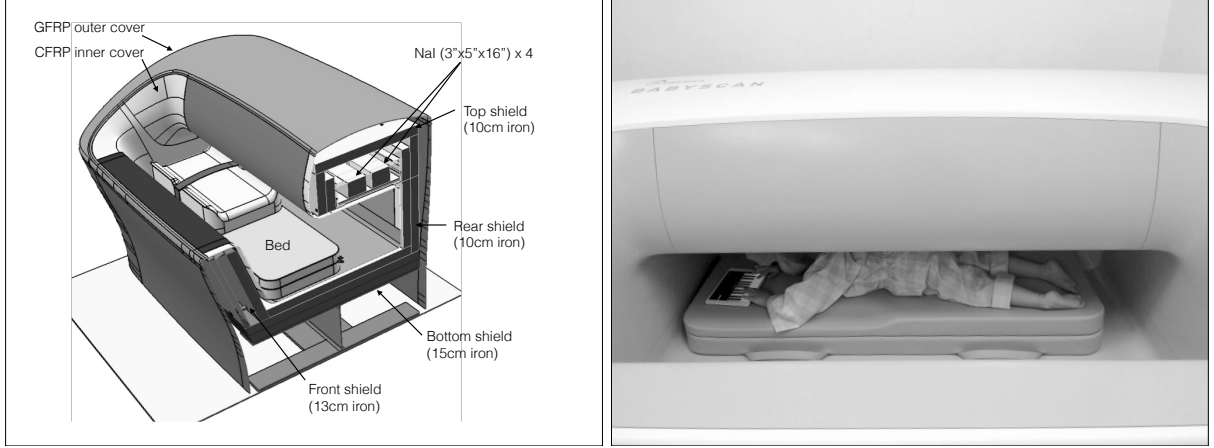


FIG. 1: Left: a cutaway view of the BABYSCAN. Right: a 4-year-old child lying on front, playing with a tablet computer, during a 4-minute measurement in the BABYSCAN.

III. BABYSCAN DETAILS

The BABYSCAN's design principles and technologies were derived from those of FASTSCAN, but in order to realize higher sensitivity, there are some crucial differences.

As shown in Fig. 1, the subject lies down inside the measurement chamber of BABYSCAN, as opposed to standing as in the case of FASTSCAN. A child can either lie on the bed supine (on their back and face up), or prone (on their stomach, face down). During development, we discovered that older children's posture tends to be more stable in the prone position, as shown in the right-hand panel of Fig. 1. Small babies, however, tend to prefer the supine position, and are more comfortable when they can also see their mother's face through the opening. Both positions are OK, as they have essentially the same efficiency.

There are four NaI detectors ($7.6 \times 12.7 \times 40.6$ cm each), arranged in a two-by-two geometry, installed in an iron-shielded compartment placed above the subject. The bottom of the NaI compartment has a window facing the subject, made of a carbon-honeycomb plate measuring 280 mm \times 860 mm. The body of a small child is therefore nearly entirely within the maximum effective range of the detectors, thereby achieving a high gamma-ray detection efficiency.

TABLE I: BABYSCAN parameters

Detector	$7.6 \times 12.7 \times 40.6$ cm NaI, four identical units, each viewed by a 3" PMT
Shield	bottom - 15 cm top, side, rear - 10 cm front - 13 cm
Outer cover	GFRP
Inner cover	CFRP
Total weight	5.7 t
Measurement time	4 min
Max. height of the subject	130 cm
Bed-detector distance	20 cm, 25 cm, 30 cm
^{137}Cs MDA	< 50 (Bq/body)

The detection efficiency can be further optimized by using a height-adjustable bed. The distance from the bed surface to the bottom of the NaI detector is either 20 cm, 25 cm or 30 cm. The left panel of Fig. 1 shows a 20 cm bed with a harness used for measuring small babies, while the right panel shows a child lying on a 25 cm bed. The bed is pulled out when a child enters/leaves the measurement chamber, and it is pushed in during the measurement.

The size of the measurement chamber is 300 mm (H) \times 800 mm (W) \times 1400 mm (L), and the bed is 400 mm (W) \times 1200 mm (L). These dimensions limit the maximum height of the subject to be about 130 cm.

The measurement chamber and the detector compartment are surrounded by 10-cm-thick SS400 iron shielding as shown in the left panel of Fig. 1. The shielding of the bottom (front) is reinforced by using an additional 5(3)-cm-thick iron. The size of the opening through which the subject enters the measurement chamber is 440 mm (W) at the top and 320 mm (W) at the bottom. This reflects an optimum balance between ease of use and maximum shielding of background radiation.

This iron structure is covered by an ergonomically designed plastic cover. The exterior surface of BABYSCAN is covered by smooth curved panels (made of glass-fiber reinforced plastic (GFRP)) colored with natural white for its gentle appearance. In order to provide a cozy space for children, the interior surface is also covered by organic surface (made of carbon-fiber reinforced plastic (CFRP)), so as to avoid the radium, thorium, and ^{40}K background from the glass in GFRP), colored by light blue which looks like being made of soft materials. These panels are precisely

assembled to eliminate the possibility of injuring baby’s skin by their gaps or edges.

All the materials used to manufacture BABYSCAN, including the bed and the tablet computer, were tested for natural radioactivity using a germanium detector prior to assembly.

Table I summarizes the BABYSCAN parameters.

IV. BABYSCAN CALIBRATION

The BABYSCAN was calibrated using a Monte Carlo N-Particle Transport Code (MCNP) [7] for a wide variety of weight and height combinations for each of the 3 bed-height positions. These calibrations were validated with 1) a 4-year-old ANSI BOMAB phantom containing 290 kBq of ^{152}Eu (made by Japan Isotope Association), and 2) 2(6)-year-old “universal” phantoms containing 3113(6226) Bq of ^{137}Cs (made by STC RADEK, St. Petersburg), for three different bed heights.

TABLE II: The results of validation measurements at the ^{137}Cs energy range for the three phantoms, using different bed heights.

Phantom	Height (cm)	Percent Difference		
		30 cm	25 cm	20 cm
Block 2y	83	-1	3	4
BOMAB 4y	105	-10	-12	-16
Block 6y	121	-2	-1	-3
Average		-5.5	-4.5	-6

In the “universal” phantom, polyethylene blocks and ^{137}Cs -containing rods are combined to make six different age and anthropometric types. We used 2- and 6-year-old phantoms to further check the BABYSCAN calibration, and also to compare the BABYSCAN’s characteristics with those of FASTSCAN.

Table II shows the results of these validation measurements at the ^{137}Cs energy range. The Phantom was counted and analyzed in the same manner that a child with that height would be analyzed. The results are consistent with the accuracy of the FASTSCAN.

Fig. 2 shows the spectra of the 6-year-old phantom (6226 Bq of ^{137}Cs) measured with the BABYSCAN (4-minutes, shown in black) and the FASTSCAN (2-minutes, shown in gray); they are installed in the same room of the hospital.

The ^{137}Cs peak count of BABYSCAN is about 8 times larger as compared to the FASTSCAN. From the increase in the number of detectors ($\times 2$) and in the measurement time ($\times 2$), one would

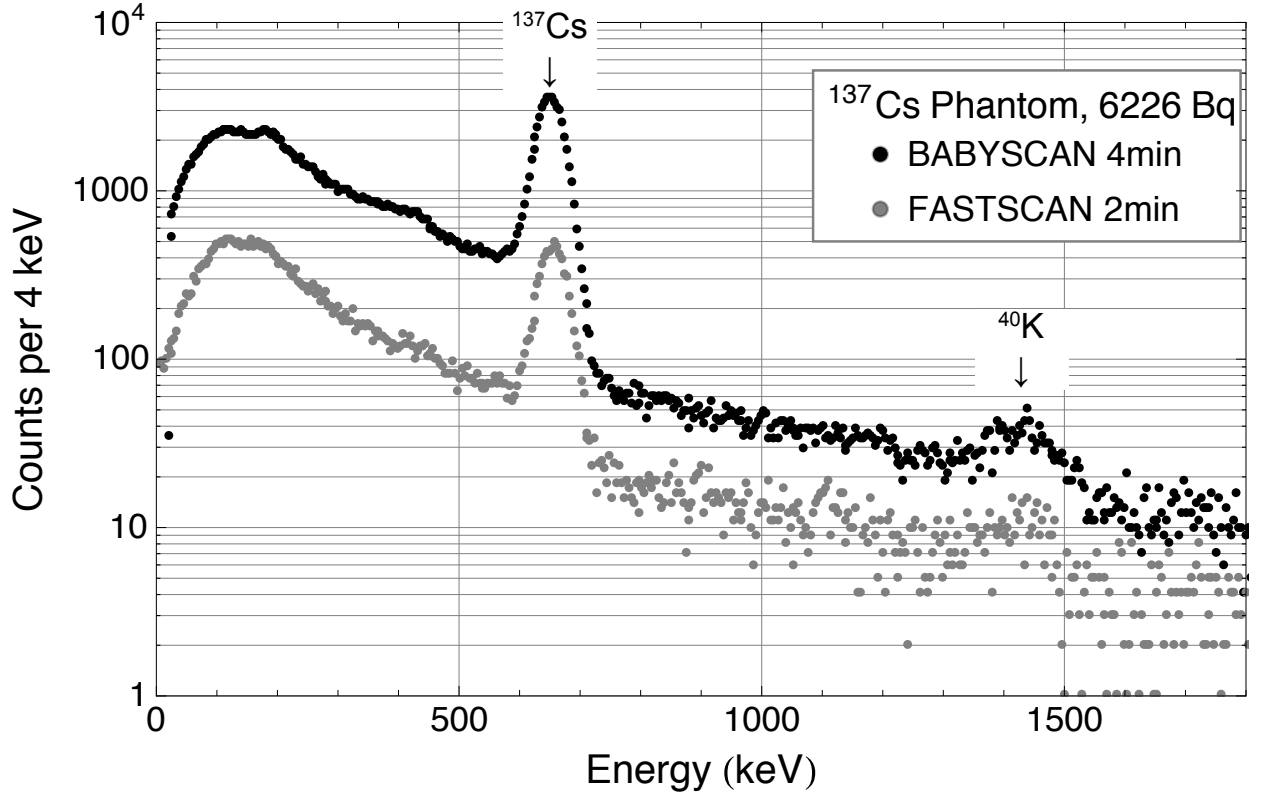


FIG. 2: Comparison of the ^{137}Cs 6-year-old phantom spectra. Black: BABYSCAN 4-minutes, Gray: FASTSCAN 2-minutes.

naïvely expect an increase of factor 4; the extra factor 2 comes from the optimized detector geometry.

The Cs-region background count of BABYSCAN is about 3.5 times higher than that of FASTSCAN, which is 13% smaller than the factor 4 expected from the differences in both the number of detectors and the measurement time. This 13% background reduction (despite a rather large opening at the top) is the result of the reinforced shielding.

V. INITIAL OPERATING EXPERIENCE OF THE BABYSCAN

The first BABYSCAN unit, installed at the Hirata Central Hospital in Fukushima Prefecture, started operation on December 2, 2013. We here demonstrate its performance based on the data of first 100 subjects, whose age distribution (minimum 3.8 months old, maximum 10 year old, mean 4.2 year old) is shown in Fig. 3, and their anthropometric parameters are plotted in Fig. 4 (minimum weight 6.5 kg, maximum weight 31.3 kg, mean 16.1 kg, minimum height 60.0 cm, maximum height 133.3 cm, mean 98.2 cm). This study was approved by the Ethics Committee of the University of

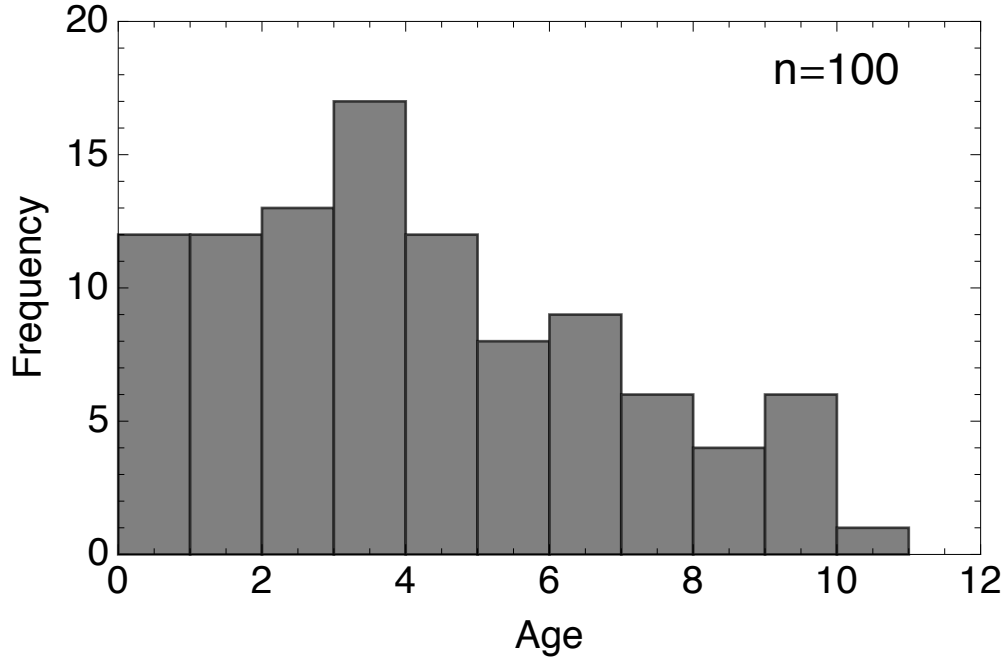


FIG. 3: Age distribution of the subjects.

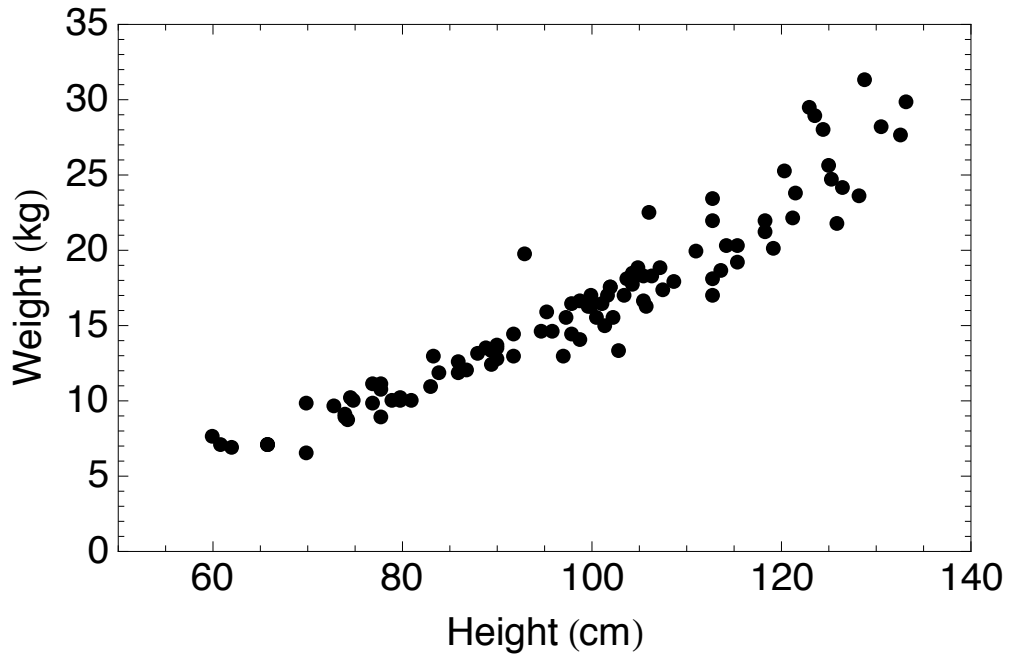


FIG. 4: Height vs weight of the subjects.

Tokyo.

We are happy to report that radiocesium was not detected in any of the 100 subjects. Nevertheless, as expected, ^{40}K was detected in all subjects. To demonstrate this, we show typical gamma-ray energy spectra in Fig. 5; the spectra shown in black dots were taken with subjects (4 minutes),

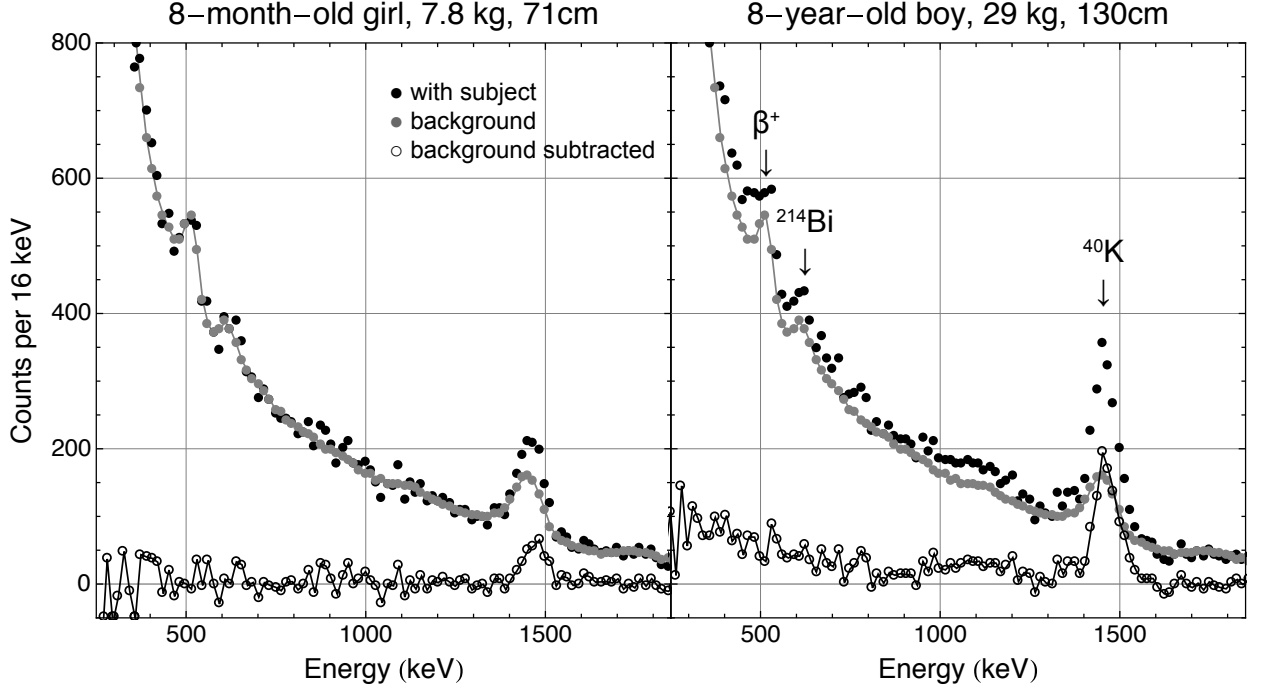


FIG. 5: Typical gamma-ray energy spectra measured with the BABYSCAN. Left: 8-month-old girl, right: 8-year-old boy. The spectra shown in black dots were taken with subjects (4 minutes), and those in gray dots were taken without subject (measured for 5 hours, normalized to 4 minutes). The background-subtracted spectra are shown in open circles.

and those shown in gray dots were taken without subject (measured for 5 hours, normalized to 4 minutes). A statistically-significant ^{40}K peak was found in each of the background-subtracted spectrum (open circles).

Fig. 6 shows the distribution of the ^{40}K activity (Bq/body) vs the weight of the subject. The data shown in open circles/filled circles/open squares were measured with the 20-cm/25-cm/30-cm bed. The data points show a linear correlation between the weight and the amount of ^{40}K in the body, with a slope of $50.7 \pm 0.9 \text{ Bq kg}^{-1}$. This is consistent with the known amount of ^{40}K in human body.

The detection of ^{40}K in all subjects and the quantification at the appropriate concentration is independent confirmation of the ability of the BABYSCAN to properly measure ^{134}Cs and ^{137}Cs . ^{40}K was reliably measured even in the smallest children, at approximately 300 Bq for an 8kg child (see Fig. 6). Since ^{40}K has only a 10% gamma yield, as compared to the 85% yield of ^{137}Cs , this is approximately the same as measuring 37 Bq of ^{137}Cs . This supports the MDAs shown in the next paragraph.

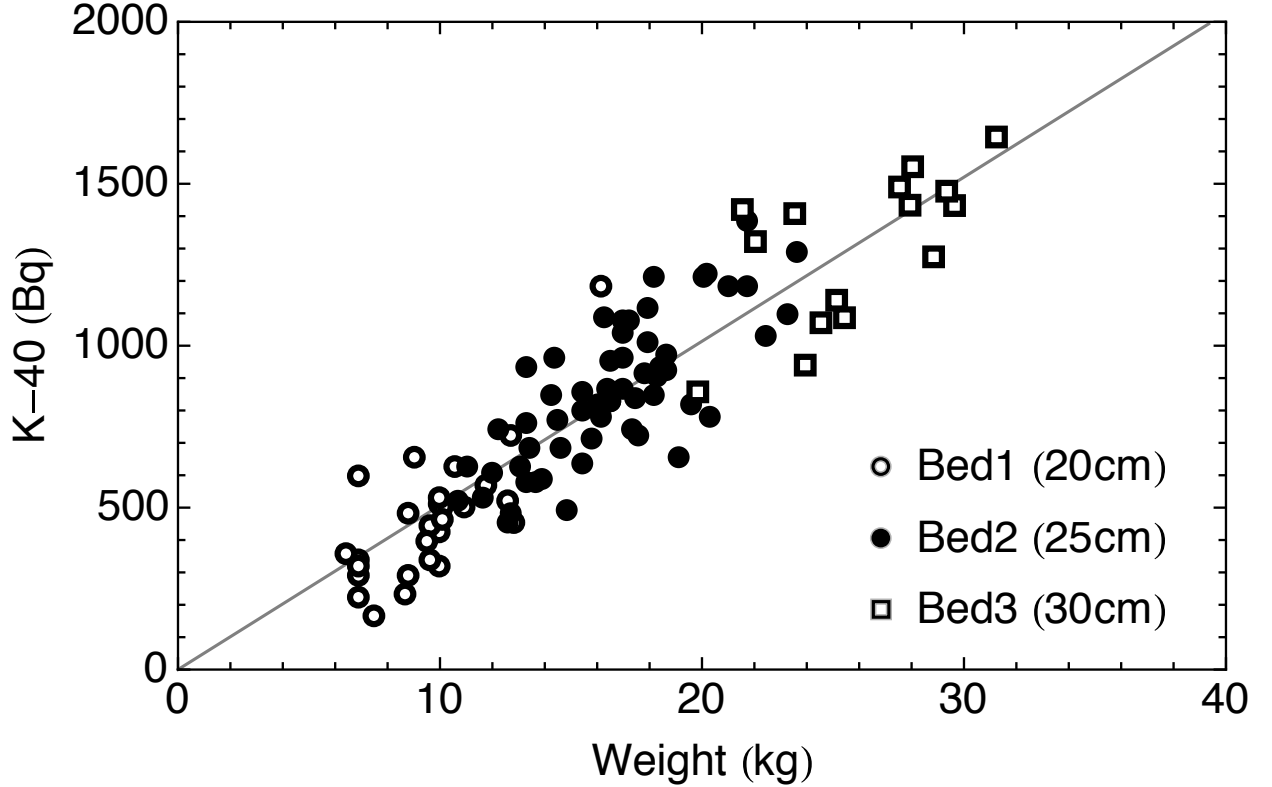


FIG. 6: The distribution of the ^{40}K activity (Bq/body) measured with the BABYSCAN vs the weight of the subject.

The minimum detectable activity (MDA) for ^{137}Cs (Bq/body), calculated for each subject, is plotted in Fig. 7 against weight (kg). Here again, data taken with 20-cm/25-cm/30-cm beds are shown in open circles/filled circles/open squares. As the bed-to-detector distance decreases, the solid angle increases and hence the MDA decreases. This plot clearly shows that our initial goal of achieving a detection limit lower than 50 Bq/body has been met.

VI. CONCLUSION

BABYSCAN, a whole body counter for small children was developed, and the first unit has been installed at a hospital in Fukushima. The radiocesium detection limit of BABYSCAN is better than 50 Bq/body, which has been realized by a careful ergonomic design, optimized detector geometry and reinforced shielding. Even with this low detection limit, radiocesium was not detected in any of the first 100 Fukushima children, while, as expected, ^{40}K was detected in all subjects. The results of larger-scale measurements with the BABYSCAN will be reported in our forthcoming publications.

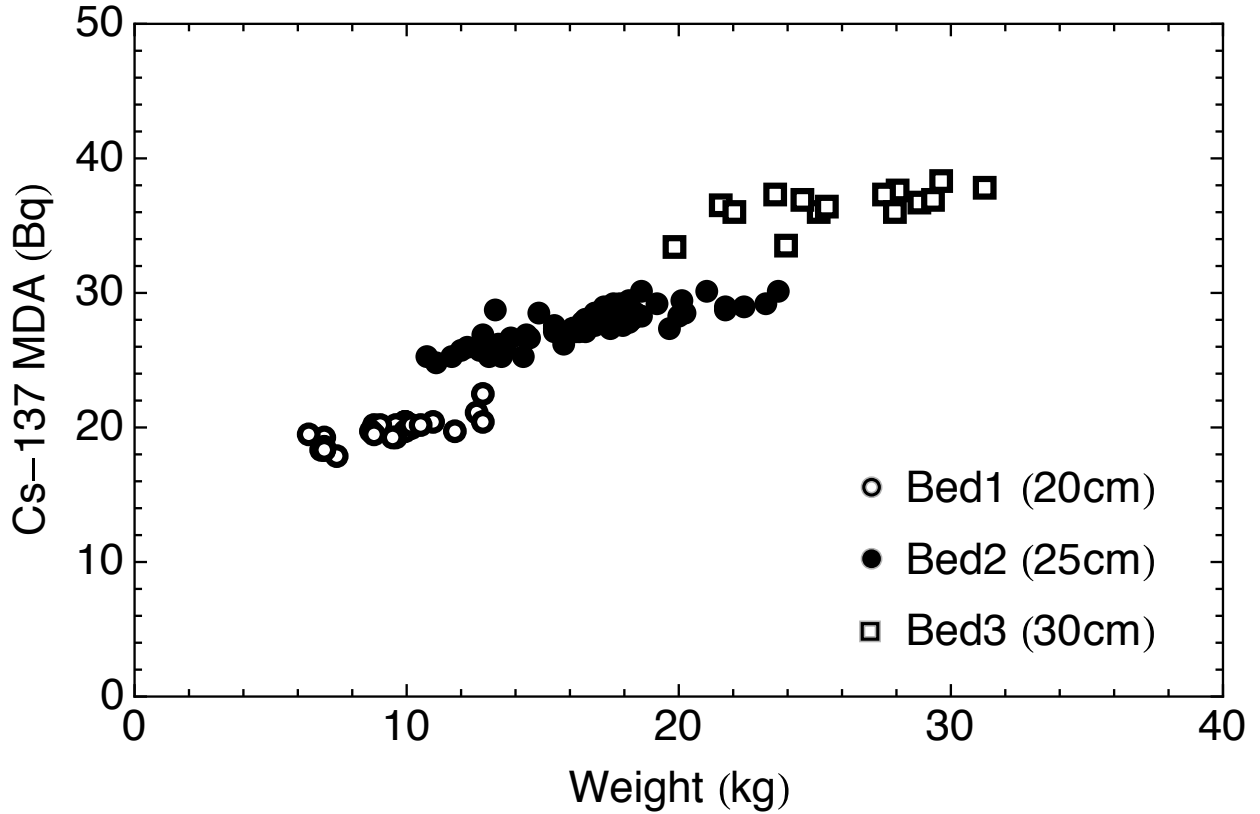


FIG. 7: The minimum detectable activity (MDA) for ^{137}Cs (Bq/body) vs subjects' weight.

Acknowledgments

The authors would like to express their appreciation to Kinuya Tagawa and Hisato Ogata of Takram design engineering for their assistance in the design of BABYSCAN. Thanks are also due to Nichinan Corporation and Shinwa kougyo Co.,Ltd. respectively for their contribution to the external panel and iron structure design and fabrication. This work was partially supported by donations by many individuals to RH through The University of Tokyo Foundation.

-
- [1] Tanaka, S. (2012) Accident at the Fukushima Dai-ichi nuclear power stations of TEPCOoutline & lessons learned. Proc. Jpn. Acad., Ser. B, Phys. Biol. Sci. **88**, 471-484.
 - [2] UNSCEAR 1988 REPORT, ANNEX D "Exposures from the Chernobyl accident". United Nations, ISBN 13: 9789211422801.
 - [3] Hayano, R. et al. (2013) Internal radiocesium contamination of adults and children in Fukushima 7 to 20 months after the Fukushima NPP accident as measured by extensive whole-body-counter surveys. Proc. Jpn. Acad., Ser. B, Phys. Biol. Sci. **89**, 157-163.

- [4] Bronson, F.L., Booth, L.F., Richards, D.C., (1984) FASTSCAN - A Computerized, Anthropometrically Designed, High Throughput, Whole Body Counter for the Nuclear Industry, Proceedings of the Seventeenth Midyear Topical Symposium of the Health Physics Society, Pasco, WA, February 5-9, 1984; also available at http://www.canberra.com/literature/invivo_counting/tech_papers/fastscan.pdf, last accessed: Feb 18, 2014.
- [5] FB gave the first proposal to Japan Atomic Energy Agency (JAEA) in spring 2012. Independently, RH received a request to make such a device from the Hirata Central Hospital, also in spring 2012.
- [6] Ishigure, N., Matsumoto, M., Nakano, T., Enomoto, H. (2004) Development of software for internal dose calculation from bioassay measurements. *Radiation Protection Dosimetry* **109**, 235-242.
- [7] Goorley, T., et al., (2012) Initial MCNP6 Release Overview, *Nuclear Technology* **180**, 298-315.